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App development to total station control and remote operation

Desenvolvimento de aplicativo para o controle e operação remota de estações totais

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Abstract: In situations that require millimeter accuracy of measurements, remote operation of total stations becomes a desirable option to reduce direct contact between the operator and the instrument, in addition to automating the transfer of data collected during the survey. This work aimed to explore, in the scope of instrument automation, the potential of using a communication protocol in the development of a cell phone application, for the control and operation of a robotic total station, model Leica TS15, from the protocol of GeoCOM communication. For the development of the application, the free MIT App Inventor web platform was used, which allowed the elaboration of the interface, as well as the programming of smartphone connection functions with the total station, among them: distance measurement, vertical and horizontal scope movement. and station rotation, automatic prism search and movement between forward and reverse measurement positions. In addition, the connection via Bluetooth was used to send commands and receive data by a smartphone with Android operating system. As a result, a mobile application capable of controlling the robotic total station was developed, allowing remote control, demonstrating the potential of Bluetooth integration between smartphone/total station.

Keywords: Total station app; Automation; Geodesy.

Resumo: Em trabalhos que exigem precisões milimétricas das medições, a operação remota de estações totais se torna uma opção desejável para reduzir o contato direto entre o operador e o instrumento, além de automatizar a transferência dos dados coletados durante o levantamento. Este trabalho teve como objetivo explorar, no âmbito da automação de instrumentos, a potencialidade de uso de protocolo de comunicação no desenvolvimento de um aplicativo de celular, para o controle e operação de uma estação total robotizada, modelo Leica TS15, a partir do protocolo de comunicação GeoCOM. Para o desenvolvimento do aplicativo, foi utilizada a plataforma Web gratuita MIT *App Inventor* que possibilitou a elaboração da interface, bem como a programação de funções de conexão de smartphones com a estação total, dentre elas: medição de distância, movimento de escopo vertical, horizontal e rotação da estação, busca automática do prisma e o movimento entre as posições de medição direta e inversa. Além disso, utilizou-se a conexão via Bluetooth para o envio de comandos e recebimento de dados por um smartphone com sistema operacional Android. Como resultado, foi desenvolvido um aplicativo de celular capaz de controlar a estação total robotizada permitindo o controle de forma remota, demonstrando a potencialidade da integração Bluetooth entre smartphone/estação total.

Palavras-chave: Aplicativo de estação total; Automação; Geodésia.

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1. Introduction

The data collection in field using topographic or geodetic methods involves the use of equipment to measure the variables of interest, such as horizontal directions, vertical angles and inclined distances. Such variables can be measured by means of equipment, such as the total station, which is one of the main equipment used in the works.

The first commercial models of total stations date back to the 70's. Initially, they were electronic distance meters coupled to a theodolite that, later, were synthesized in a single equipment, which came to be called a total station. (PETRIE; TOTH, 2018). A few decades later, total stations with servo motors were launched on the geotechnology market, which allow the performance of rotational movements of the instrument around its main axis and the bezel in relation to the secondary axis (LEVIN; NADOLINETS; AKHMEDOV, 2017). In addition to these, it is worth mentioning the total stations that have the ability to recognize and automatically aim targets, being called robotic total stations (CARVAJAL; VEIGA, 2019).

The collection of geodetic data corresponds to a structured sequence of logical steps and, as result, offers a determined number of observations for one or several physical phenomena, which are processed and transformed into information of interest, usually geodetic coordinates. The evolution of data collection occurs simultaneously with technological advances in measuring equipment. Initially, observations were recorded on paper, reducing the efficiency of the process and limiting the amount of data collected, also contributing to an increase in the probability of gross errors occurring during the collection process. Currently, total stations, GNSS (Global Navigation Satellite System) signal receivers, digital levels and other measurement equipment have the ability to collect a large amount of data compared to data collected in the past in the same time interval. This is the result of the technological evolution that brings with it the concept of automation; can be defined by the fact that there is restriction of human intervention in the data collection process.

Technological development with automation has been one of the main focuses in the scope of geodetic surveys, since it provides significant impacts on the accuracy of the collected data, reducing errors and increasing productivity (TEDESCHI; FAGGION; ANDOLFATO, 2017; CARVAJAL; VEIGA, 2019). Such progress is due to the need, on the part of different areas of science or industry, to employ more efficiency in data collection, resulting in agility, better accuracy through automatic recognition systems ATR (Automatic Target Recognition) or angular encoders, and also a reduced risks associated with the process of collecting data in the field by operators (MEDEIROS; FAGGION; ALVES, 2020).

Technological advances allowed the integration of computer applications in geodetic monitoring techniques, enabling the use of monitoring parameters for tunnels, roads, dams and structures. As result, all the technological evolution in the area of geodetic sensors has provided a large amount of data, more confiability of the information acquired and efficiency in the process of obtaining data (AGUILAR; CARVAJAL, 2014).

From this perspective, the possibility of developing applications and free programs for certain types of equipment through communication protocols has been absorbed by the geodetic sensor industry. This concept translates into the possibility for users to develop their own applications to achieve specific objectives that are not standardized in commercial solutions. The possibility that users can carry out their own routines to automate data collection or generate information in the field is possible by opening the source codes of geodetic sensors and communication protocols, which allow the control of their sensors.

Some examples that can become a general solution for an industry sector or for science areas through the automation of a total station are: applications for automatic recognition of prism (OMIDALIZARANDI *et al*., 2018), trigonometric leveling with total stations (ZOU *et al*., 2017), geodetic monitoring (JÄGER *et al*., 1999; WILKINS *et al*., 2003; LUTES, 2002; ENGEL; SCHWEIMLER, 2016), rail track monitoring (GIKAS; DASKALAKIS, 2008), industrial monitoring (SETAN; IDRIS, 2008) or science-oriented applications, such as the Qdaedalus system by Hauk *et al*. (2017).

Currently, one of the highlights regarding the application of automation of total station surveys is the integration of sensors, which aims to carry out observations of physical phenomena by more than one sensor, synchronizing the collection. Thus, it is possible to associate accelerometers to terrestrial geodetic sensors with a total station or sensors contained in other instruments, such as GNSS receivers, during the geodetic monitoring of a structure or also between different geodetic sensors (MEDEIROS; FAGGION; ALVES, 2020). This last possibility also opens the door to experimental integration using low-cost sensors, as presented in Carvajal and Veiga (2019) who developed a network of temperature sensors with Arduino microcontrollers to calculate the first speed correction in monitoring environmental parameters. , integrating in the distance observations obtained with the electronic meter of a total station.

One of the characteristics of modern total stations is the ability to control and operate remotely, either through dedicated remote controls or through some type of interface. When considering measuring instruments with high precision and sensitivity, it is essential to idealize their remote operation, since the reduction of direct contact during the operation of the instruments would minimize possible sources of errors.

It is also noteworthy that the user's movement around the instrument can cause unwanted vibrations in the tripod/station set. Thus, thinking of operating a total station remotely is not merely a convenience, but a way of improving the quality of work and, consequently, the accuracy obtained.

Another advantage of remote operation is that in high-precision geodetic surveys, temperature, humidity and atmospheric pressure measurements are required when distance measurement is performed by Electronic Distance Meters (EDM), and an operator close to the instrument can create a microclimate that interferes in the measurements of these values. This procedure is necessary because the distance calculated by the EDM is determined from the knowledge of the speed of propagation of light in vacuum. However, in high-precision geodetic surveys, it is necessary to consider the value of the speed of light propagation in the environment where the measurement is being carried out. For more details on Electronic Distance Meters, it is recommended to consult Jerke (2019).

Within the scope of geodetic sensors and the advancement of mobile technology, its implementation and constant improvement in smartphones can be highlighted. One of the points currently explored is the use of GNSS receivers (URADZIŃSKI; BAKUŁA, 2020) and imaging sensors, applying techniques such as Structure from Motion to extract three-dimensional models to calculate volume (WRÓŜYŃSKI *et al.*, 2017) or the 3D reconstruction of objects of geomorphological interest (DABOVE; GRASSO; PIRAS, 2019), and the detection of surface displacements (ALVES *et al*. 2020). he presence of several sensors also makes it possible to combine them for data synchronization and information modeling from smartphones (FISSORE *et al*., 2017).

In this sense, this work aims to develop an application to control a total station, as well as to present the concepts and methods involved in the communication process between geodetic survey equipment. The MIT App Inventor platform was used for the development of the control application in the Android operating system. The GeoCOM protocol from Leica Geosystems was used to communicate with the total station, from sending codes and receiving data collected via the communication interface on the smartphone with Bluetooth connection.

2. Methodology

The development of the interface to control the total station, using smartphone, involved the knowledge of the communication protocol available by the instrument manufacturer and the choice of the operating system in which the application was developed. In this work, the Android operating system and the GeoCOM protocol were used in order to establish communication with the total station Leica TS15.

It should be noted that the characteristics corresponding to the smartphones used for the development of the communication interface designer were considered, such as the screen size, input devices, communication sensors and memory. The usability of the application in the implemented functions was also considered, since mobile applications must be focused on solving problems for users.

2.1. Communication Process

Communication consists of the exchange or sharing of information, through material means or not, with the objective of transmitting data between two or more individuals and/or devices (FOROUZAN, 2010), as illustrated in Figure 1.

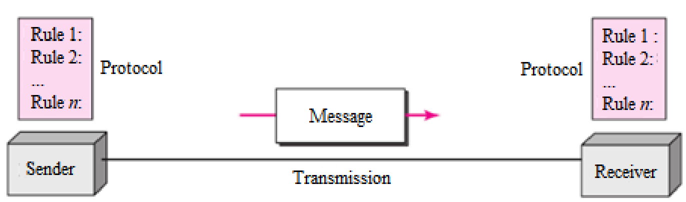

Figure 1 – Components of a communication system.
Source: Forouzan (2010).

According to Forouzan (2010, p. 4), data communication between devices requires the association of software and hardware, consisting of five key elements:

> "Message: (...) information (data) to be transmitted. Among the popular forms of information, we have: text, numbers, figures, audio and video;
> Sender: (...) device that sends the data message. It can be a computer, workstation, telephone, television, and so on;
> Receiver: (...) device that receives the data message. It can be a computer, workstation, telephone, television, and so on;
> Transmission: (...) physical path through which a message travels from the sender to the receiver. Some examples of transmission media are as follows: twisted pair cable, coaxial cable, fiber optic cable and radio waves.
> Protocol: (...) set of rules that control data communication. Represents an agreement between communication devices. Without a protocol, two devices can be connected, but without communicating (...)"

Among the means of communication currently used, there is the connection of devices through Bluetooth technology, present in most electronic devices. The exchange of information using Bluetooth occurs through the frequency band of 2.4 GHz, defined as piconet, and can reach a connection range of 100m, depending on performance (LOUREIRO *et al*., 2003). During communication, the devices work in an established way as a master-slave, the master being the one who initiates the connection, limited to up to 7 slaves per master (LOUREIRO *et al*., 2003).

The presence of these devices in smartphones, combined with the possibility of developing applications that enable the exploitation of such technology, allows the establishment of communication and/or control of equipment and other devices, dispensing with direct physical contact.

The connection between smartphones and total stations can be made via cable, radio link or Bluetooth, in request/response mode, in both directions, in which both are senders and receivers and that for each request asked by the smartphone, a response is sent by the season. Bluetooth was the means of communication chosen to exchange messages between the devices covered in this research. Communication, in this case, is also parameterized through a protocol that will allow the sending of information and its decoding (Figure 2).

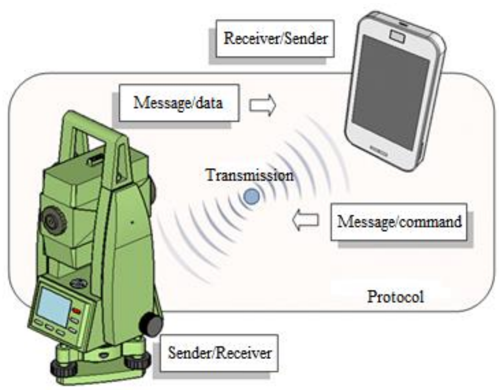

Figure 2 – Smartphone total station communication system.
Source: The authors (2022).

For communication to take place, it is initially necessary to create a program that can generate the questions and understand the total station's responses in the format established by the protocol. Developing such a program, for mobile devices, requires the creation of an application, which will manage the communication process. Several programming languages can be used, such as Python, for example. There are also open-source web platforms that allow the development of application programs for the Android operating system. The company Google Inc, in partnership with the Massachusetts Institute of Technology, has made available a free platform, called MIT App Inventor, which aims to develop applications for Smartphones, with the Android operating system, through application design-oriented programming, allowing the exploration of its functionality and devices such as GNSS, accelerometer, Web connections and Bluetooth (FINILOZA *et al.*, 2014).

Several researches on the applied use of mobile technologies are currently being disseminated, among them the smartphone application developed for the geometric design of roads that performs the calculation of all the elements of the curves, such as: routine, calculation of simple curves, calculation of curves with spiral transition, staking of simple curves and staking of curves with transition (OLIVEIRA; VAZ, 2016).

Another example is Calc-Geo, an application with real-time processing for topographic survey in a coffee production area. Tests carried out in these areas showed that its use can provide the coffee grower with an error of less than 1% in defining the amount of coffee plants that he must acquire/buy for a given planting area. (SILVEIRA *et al*., 2017). Finally, Mlenek *et al*. (2017) developed an application on the Android studio platform aimed at dynamic monitoring of structures through smart sensors.

2.2. Communication Protocol

In recent years, several brands of topographic/geodesic instruments have emerged, each with its own communication protocols. However, in this article we chose the communication protocol from Leica-Geosystems, called GeoCOM, for a brief example and use in the remote operation of equipment due to the availability of the TS15 total station for this research. The TS15 has 1" angular accuracy, linear accuracy ± (1mm + 1.5 ppm), and ATR capable of locating and tracking prisms, during the survey carried out, with an accuracy of 0.3 milligons (mgon) (LEICA, 2015; MEDEIROS, 2020).

2.2.1. GeoCOM Protocol

According to Leica (2006), with this protocol it is possible to write applications based on MS-Windows and/or for any other platform that supports communications based on ASCII. The company has a set of instruments that are part of the TPS1000, TPS1100 and TPS1200 software family. The TPS system organizes and controls the internal actuation of various sensor elements and gives access to a series of functions. In Leica (2006) it is possible to have access to all the functions that can be manipulated and controlled by the GeoCOM Client, a software package developed by Microsoft Visual Basic and VBA.

Communication takes place between a client and a server and is carried out over serial communication lines. The communication architecture between the requesting device and Leica equipment can be seen in Figure 3.

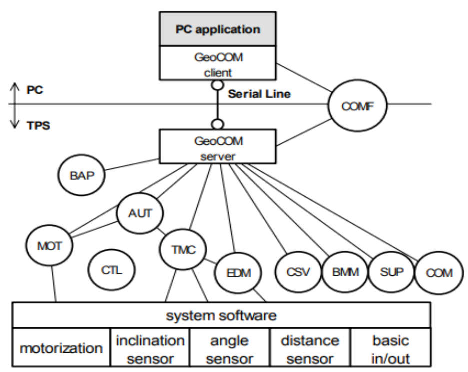

Figure 3 – GeoCOM communication structure.
Source: Adapted from Leica (2006).

The circles represent the functions, which are organized into subsystems (Leica, 2006):

- AUT – Automation: this module has functions that control, for example, automatic target recognition, face change function or position function.
- BMM - Basic Man Machine: These are basic communications functions such as setting alarm or related things.
- COM – Communication: this module works with basic communication parameters, most of these functions are related to both client and server parts.
- CSV - Central Services: this module has functions to acquire or configure central/basic information about the TPS1200 instrument.
- CTL - Control Task: This module contains control task system functions.
- EDM - Electronic Distance Meter: This module offers a series of functions that measure distances.
- MOT – Motorization: module responsible for controlling the movement and speed of movement of the equipment.
- SUP – Supervisor: functions for controlling some general values of a TPS1200 instrument.
- TMC - Theodolite Measurements and Calculation: It is the central module for collecting measurement data.

Commands using GeoCOM begin with the character set "%R1Q," followed by a command identification number, such as the number 17017 to measure distance and angle. For every command, an ASCII response is sent by the instrument, which in turn starts with "%R1P" followed by return codes and parameters that depend on the ASCII request sent. Table 1 shows examples of syntax for sending functions to receive information.

Table 1 – Syntax example of some functions.

Example of functions			
Function	**GeoCOM Command**	**Request ASCII**	**Response ASCII**
Serial Number	CSV_GetinstrumentNo	%R1Q,5003:	%R1P,0,0:0,SerialNo
Instrument Type	CSV_GetInstrumentName	%R1Q,5004:	%R1P,0,0:0,Name
Date/Time	CSV_GetDateTIme	%R1Q,5008:	%R1P,0,0:0,Data,Hour,Minute,Second
Horizontal Angle	BAP_MeasDistAngle	%R1Q,17017:2	%R1P,0,0:0,dHz,dV,dDist,DistMode
Vertical Angle	BAP_MeasDistAngle	%R1Q,17017:2	%R1P,0,0:0,dHz,dV,dDist,DistMode
Inclined Distance	BAP_MeasDistAngle	%R1Q,17017:2	%R1P,0,0:0,dHz,dV,dDist,DistMode
PPM/mm	TMC_GetSlopeDistCorr	%R1Q,2126:	%R1P,0,0:0,total_Ppm,PrismCorr
Prism Constant	TMC_GetPrismCorr	%R1Q,2023:	%R1P,0,0:0,PrismCorr

Source: Adapted from Leica (2006).

2.3. App Development

Within the field of software development and applications, there are different models that enable the initial organization for the development of a particular application. In this regard, it was decided to adopt the Linear Sequential Model, also defined as the Waterfall Model, for the elaboration of the application creation stages, in a well-defined way. According to Gomes and Melo (2014), the use of App Inventor for the development of applications does not exclude the need for a minimal design process, in order to serve as a guide for the project.

For app development, MIT App Inventor provides two work environments: the App Inventor Designer and the Block Editor. Each workspace features a distinct functionality for authoring. The first provides resources for the construction of the interfaces that are intended to be made available to the user of the application, such as buttons, windows, images, among other characteristic elements of interfaces, in addition to linking functions present in the cell phone, such as access to accelerometer data and Bluetooth. The second platform environment aims to develop the items created in the first step, in order to guide the respective procedures through the block connection architecture, generating the instructions and events of interactions with the cell phone (FINILOZA *et al*. 2014).

From this, four stages were defined for the development of the application, exemplified in Figure 4.

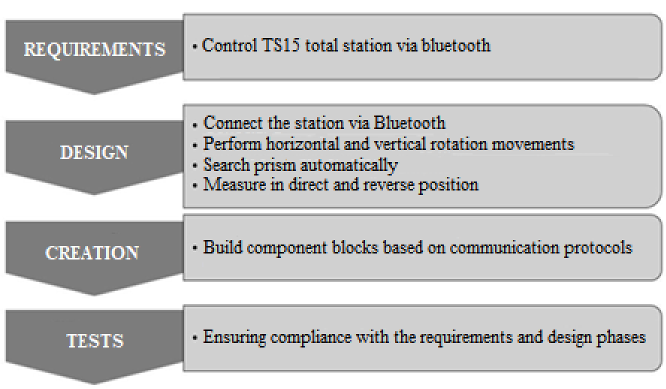

Figure 4 – Application development steps.
Source: The authors (2022).

The first step involved the initial requirement, in which the means of communication for controlling the total station was defined. In order to explore the wireless control and sensors available in smartphones, it was decided to use communication via Bluetooth. However, it should be noted that opting for Bluetooth technology imposes a restriction related to the distances between the two devices.

The application design was established after defining the actions to be performed by the application's total station on the smartphone. In addition to the function of activating/deactivating the remote connection via Bluetooth, were implemented the movement function (turning) in relation to the horizontal and vertical axes, the prism search function for automatic prism location and the measurement of angles and distances in Direct Pointing (PD) and Reverse Pointing (PI). In Figure 5, the application sketch is presented, in which three main screens were projected.

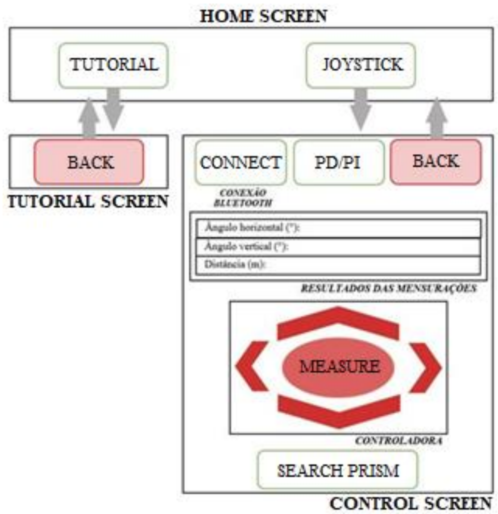

Figure 5 – Sketch of the application's logical functioning.
Source: The authors (2022).

The first screen is the application opening screen, called Home screen, which presents general information about the program. On the second screen, named Tutorial Screen, the application's functionalities are presented. The third, Control Screen, contains the user interfaces for controlling and measuring with the instrument.

It is noteworthy that, despite the implementation of the connection function with the total station within the application, there is a need to activate the Bluetooth sensor of the smartphone and the total station before establishing communication.

Communication between smartphone and total station was implemented with the app's Connection button. When you activate it, the Connection screen opens and the nearby devices with active Bluetooth are listed there. To establish communication, you must select the device referring to the total station and enter the defined connection password, if any.

The instrument movement control was implemented considering the three types of rotation:

a) Horizontal rotation of the equipment, which can be performed using the arrows to the right and left in the joystick scheme.
b) Rotation of the telescope towards the zenith and the nadir, also with the joystick.
c) Tilting of the scope (direct and reverse positions) through the specific button.

To read the horizontal direction, zenith angle and inclined distance, a button was designed in the center of the joystick. The data sent by the station to the smartphone is shown in the field just above the movement keys.

3. Results

The experiment resulted in an application for Android phones capable of remotely controlling the Leica TS15 robotic total station. It should be noted that, as it is a test version application, a reduced number of functions were inserted. However, the abundance of protocols present in the instrument and the wide development possibilities in App Inventor contribute to the possibility that future versions of the application can be created containing a wider range of functions.

Figure 6 presents the interfaces created for the application that was named TS15 Operator and has command screens that allow interaction with the operator.

Figure 6 – TS15 operator screens.
Source: The authors (2022).

Figure 6A shows the application's home screen, from which the operator has the option to click on “TUTORIAL” if they want to see instructions to get to know the application, or the option to click on “JOYSTICK” if they want to control the TS15 Station.

Figure 6B shows the tutorial screen, where the operator can read the application's information and usage instructions.

Figure 6C shows the joystick screen, where the operator must first establish communication via Bluetooth by clicking on “CONECTAR” and then selecting the total station device. Once communication has been established, the operator can freely operate the TS15 through the buttons available on this screen, and when clicking on “PROCURAR PRISMAS” the total station performs the automatic prism search function and when clicking on “MEDIR” the values appear. of horizontal angle, vertical angle and inclined distance measured by the TS15.

Figure 7 shows some of the blocks created to execute the desired control functions in the Block Editor, developed after the design of the interfaces based on the communication protocols provided by Leica GeoSystems.

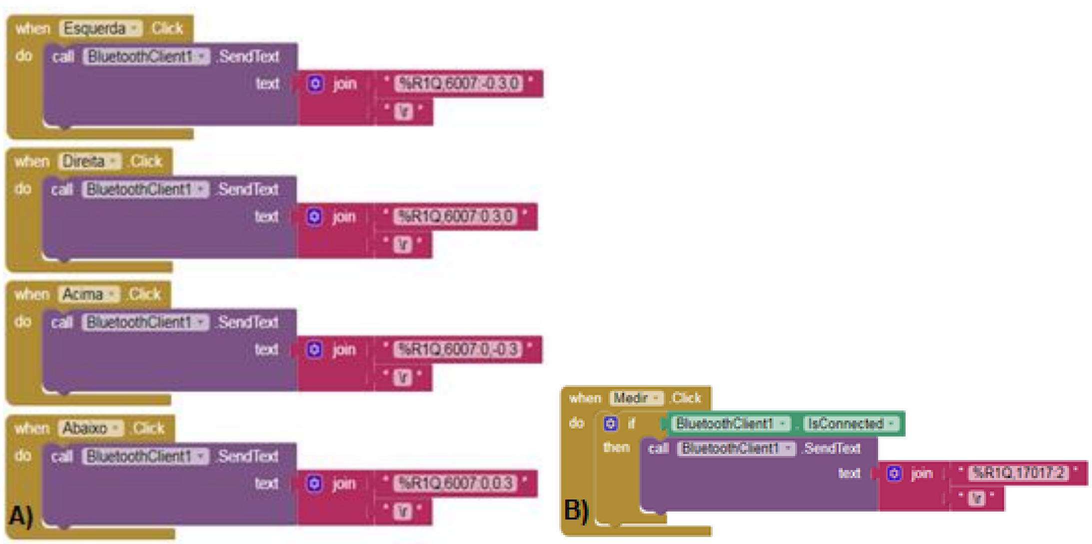

Figure 7 – Joystick Command Blocks.
Source: The authors (2022).

An example of the functions is shown in Figure 7B, which shows the command block of the “MEDIR” button. This block performs the following function: when the “MEDIR” button is clicked, the smartphone will send via Bluetooth the code “%R1Q,17017:2” to the total station which, in turn, upon receiving the code, performs the measurement and returns to the smartphone the values of horizontal angle, vertical angle and inclined distance in the spaces indicated in Figure 6C.

3.1. Discussion

The application was developed following usability standards that result in a simple interaction between user and total station. The use of these standards is mainly aimed at favoring intuitiveness, in order to facilitate the understanding and operation of the equipment, since for many users the operation of a total station is not as understandable as a cell phone application and this can be verified with young students who do not have so much familiarity with the total station interface, but when operating through the application they did not present difficulties due to the intuitiveness of the developed application.

The ability to operate a total station remotely instead of operating directly at the station interface brings numerous benefits to the automation of geodetic surveying. One of these benefits is the minimization of the operator's influence on the instrument, avoiding the transmission of vibrations to the tripod/station assembly and reducing the possibility of involuntary movements due to shocks with the tripod/instrument when taking measurements. Another benefit is the attenuation of the effects of temperature variation close to the instrument due to human presence, because in high precision surveys the temperature measurement is an important factor and the human presence in the equipment can affect the measurement of these values.

In addition to these benefits, an important feature of this tool is the possibility of creating applications aimed at the specific needs of the user, especially when there is repeatability of surveys, such as monitoring structures, because from the application the user can make some adaptations so that the approximate values of horizontal and vertical angles of certain points are saved in memory and that, when taking measurements, the application can already control the station to read these points.

Another point to be observed with the use of the developed application is the elimination of the data transfer stage of the survey. When using the direct operation on the station interface, to work with the values collected, it is necessary to transfer data to the device to be processed. In the application operation, the transfer of the amounts collected is done automatically during the survey, since the data is already entered in the smartphone and can be applied in the processing of the survey.

Finally, the developed application proved to be functional, allowing remote control of the robotic total station, which demonstrates both the potential of Bluetooth integration between smartphone/total station and the simplified operability of the MIT platform.

4. Final Considerations

Understanding the principles of communication, data transmission and operation of total stations provide the necessary support for the development of the application, being a fundamental step in the process of automation of geodetic surveys.

The main objective of this work was to develop and experiment an application that would allow remote control and operation of robotic total stations. As a working premise, this application should be able to establish communication with the measuring instrument, through the communication protocol established by the equipment manufacturer, command the movement of the instrument and perform the measurement of an aiming system basically composed of a prism reflective.

In this way, it is concluded that the creation of applications to control geodetic equipment, such as robotic total stations, contributes to the user's operating intuitiveness and to the reduction of the observer's influence during the survey process, making the work safer and the risk of movement of the tripod/station assembly is reduced.

As the present research was elaborated with a view to the automation of geodetic surveys, the application was developed with this theme in mind, but its function is not limited to that, and can be changed or adapted for different purposes. This type of work methodology has an interesting range of applications, because whenever there is repeatability of tasks, it becomes interesting to use applications that operate remotely.

It should be noted that the potentialities raised in this research contributed to the development of a doctoral thesis in the Graduate Program in Geodetic Sciences at the Federal University of Paraná, which will continue the development of an application that automates the collection and processing of data in geodetic monitoring of dams, where survey repeatability is present.

It is also recommended that, in future works, the various functionalities that make up the geodetic survey process are inserted, so that this study can be used in different types of surveys or even in other geodetic instruments, such as GNSS receivers, terrestrial laser scanners. , etc. Another recommendation is that this integration is also disseminated to other communication protocols existing in other companies in the field, such as Topcon, Trimble, etc.

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